



## Original Article

## Sleep duration and obesity among adults: a meta-analysis of prospective studies



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## ABSTRACT

**Background:** Results from longitudinal studies on sleep duration and incidence of obesity remain controversial.

**Methods:** PubMed and Web of Science updated on 20 February 2014 were searched for eligible publications. Pooled odds ratio (OR) with 95% confidence interval (CI) was calculated using a random-effects model.

**Results:** Eleven published articles were included, involving 197,906 participants for short sleep duration and 164,016 participants for long sleep duration. Compared with the normal sleep duration, the pooled OR for obesity was 1.45 (95% CI, 1.25–1.67) for the short sleep duration overall. After removing the three studies that had strong effects on heterogeneity, the pooled OR was 1.25 (95% CI, 1.14–1.38). The positive association was consistent among all subgroups analysis except in the European group (OR, 1.45; 95% CI, 0.79–2.64). No significant association was found between long sleep duration and risk of obesity overall (OR, 1.06; 95% CI, 0.98–1.15) and in subgroup analysis.

**Conclusion:** This meta-analysis indicated that short sleep duration was significantly associated with incidence of obesity, whereas long sleep duration had no effect on future obesity among adults.

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## 1. Introduction

Overweight and obesity are severe health burdens both in developed and developing countries. About 500 million adults worldwide were obese in 2005, and this number has doubled since 1980 and is projected to increase to 1.1 billion by 2030 [1]. In simplistic terms, obesity develops when energy intake is greater than energy expenditure. Although diet and physical activity play an important role in the risk of weight gain and obesity, a potential additional factor may be sleep.

During the past couple of decades, several cross-sectional studies have found a significant association between short sleep duration and increased prevalence of obesity or weight gain in adults from various countries [2,3]. Some of these studies also observed a U-shaped association between sleep duration and body mass index (BMI). By definition, the findings of cross-sectional studies give little information about the direction of causality. Obesity is a strong risk factor for diseases such as sleep apnea and arthritis that may limit an individual's ability to sleep [4]. Longitudinal researches can overcome the problems inherent in cross-sectional studies, and thus can

provide more convincing results [5]. However, the results of longitudinal associations between sleep duration and obesity were conflicting [4–6]. Most recently, a systematic review of a cohort study by Magee and Hale concluded that the association between sleep duration and subsequent weight gain is unclear in adults [7]. However, they did not provide a quantitative risk estimate. Besides, other studies [8–11] have since been published. Therefore, we conducted a meta-analysis of prospective studies to: (1) first assess the risk of obesity for the short sleep duration vs normal sleep duration as well as the long sleep duration vs normal sleep duration; (2) then evaluate the modification of key covariates to the association between sleep duration and obesity risk among adults; (3) and explore the heterogeneity among studies and publication bias.

## 2. Methods

## 2.1. Literature search and selection

A search of the literature up to 20 February 2014 was performed using the databases of PubMed and Web of Science using the following search terms: (sleep duration or sleep time), (obesity or weight gain), and (cohort) without restrictions. Moreover, we reviewed the reference lists from retrieved articles to search for further relevant studies.

Two investigators independently reviewed all identified studies, and studies were included if they met the following criteria: (1) a

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prospective design among adults; (2) the exposure of interest was sleeping duration categories; (3) the outcome of interest was obesity; (4) multivariate-adjusted hazard ratio (HR) or odds ratio (OR) with 95% confidence interval (CI) was provided; (5) the most recent and complete article was chosen if a study had been published more than once.

## 2.2. Data extraction

The following data were extracted from each study by two investigators: (1) name of the first author; (2) year of publication; (3) origin of country; (4) ethnicity of study population; (5) follow-up years; (6) gender distribution and mean age of study population; (7) sample size and number of cases; (8) methods to assess sleep duration; (9) methods to assess obesity; (10) HR or OR with 95% CI (adjusted by the most confounders in the original studies) for short sleep duration and long sleep duration as compared with the normal sleep duration; and (11) number of covariates adjusted.

## 2.3. Statistical analysis

The pooled measure was calculated as the inverse variance-weighted mean of the logarithm of OR with 95% CI to assess the strength of association between sleep duration (short or long) and risk of obesity. The inverse variance-weighted method was implemented with the option 'randomi' in the module 'metan', and the weight is inversely proportional to the standard error of the OR. Heterogeneity was assessed using  $I^2$  [12]. The univariate random-effects meta-regression analysis using residual (restricted) maximum likelihood was performed to assess the potentially important covariates that might exert substantial impacts on between-study heterogeneity. The sensitivity analysis [13] was conducted to evaluate the key studies that have substantial impact on the between-study heterogeneity, and then re-estimate the effect after excluding the studies that exert substantial impact on the between-study heterogeneity. An influence analysis [14] was also performed in which one study at a time was removed and the rest were analyzed to evaluate whether the results could have been affected markedly by a single study; an individual study was suspected of excessive influence if the point estimate of its omitted analysis lay outside the 95% CI of the combined analysis. Publication bias was evaluated using the Egger regression asymmetry test. Statistical analysis was conducted using Stata version 11 (StataCorp LP, College Station, TX, USA).

## 3. Results

### 3.1. Literature search and study characteristics

The detailed steps of our literature search are shown in Fig. 1. On the basis of the search strategy and inclusion criteria, 17 papers seemed to be eligible after reading the title or abstract. After the full texts had been read, two papers [15,16] were excluded because of duplicate reports from the same study population; two papers [17,18] were excluded because they provided data only on the prospective association between sleep duration and weight gain only; and two papers [19,20] without HR or OR values were also excluded. The remaining 11 articles [4–6,8–11,21–24] were included in this meta-analysis. Results from three articles [5,11,23] were presented according to sex, and these were considered as separate studies in the data analysis. One article [9] reported the results not only in total but also according to different sex, thus it was considered as one study in the overall analysis, and then the sex-specific results were used in subgroup analysis by sex. Among the 11 articles, the majority of studies reported OR by using logistic regression, whereas only two articles [4,9] reported HR by using Cox

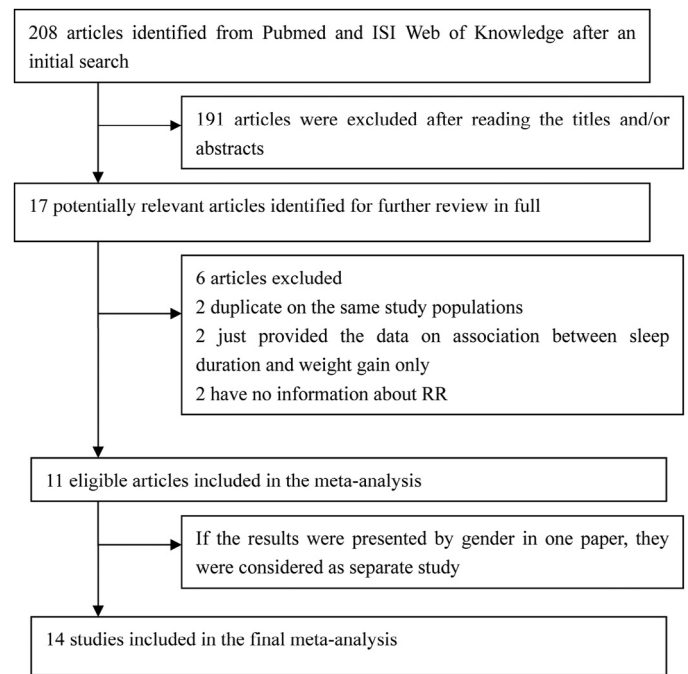


Fig. 1. Selection of studies for inclusion in this meta-analysis.

regression. The detailed characteristics of the 14 studies included in the 11 articles are shown in Table 1.

Self-reported sleep duration was supplied in all of the included studies. The referent categories were 7 h [4,8,21,22], 7–8 h [5,6,9,11,24],  $\geq 7$  h [10], and 5–7 h [23], respectively. Twelve studies defined short sleep as a duration of  $<5$  or  $\leq 5$  h, and the remaining two articles [6,24] defined it as  $<6$  or  $\leq 6$  h. Long sleep was defined as a duration of  $>7$  h [23],  $\geq 8$  h [9,21,24], or  $\geq 9$  h [4,5,8,11,22].

Obesity was defined as BMI  $\geq 30$  kg/m<sup>2</sup> in European [9,22] and American [4,10,11] studies and as BMI  $\geq 25$  kg/m<sup>2</sup> in Japanese [5,8,21,23,24] studies. However, one study in Canada [6] defined the outcome as overweight/obesity (BMI  $\geq 25$  kg/m<sup>2</sup> for French-Canadians).

### 3.2. Quantitative synthesis

The results are summarized in Table 2.

#### 3.2.1. Short sleep duration and obesity

Fourteen prospective studies involving 197,906 participants were included in the short sleep duration meta-analysis. The overall result indicated that short sleep duration was significantly associated with the risk of future obesity (OR, 1.45; 95% CI, 1.25–1.67;  $I^2 = 66.2\%$ ) (Fig. 2). The association (OR, 1.48; 95% CI, 1.24–1.78;  $I^2 = 64.4\%$ ) did not change materially after excluding studies reporting HR [4,9].

Four articles [5,9,11,23] reported separate results for men and women, one study's participants [24] were male, and one study [4] was conducted among females. Thus, pooled measures were calculated separately by gender for these studies. The statistically significant associations were observed both in males [5,9,11,23,24] (OR, 1.65; 95% CI, 1.24–2.19;  $I^2 = 74.4\%$ ) and in females [4,5,9,11,23] (OR, 1.25; 95% CI, 1.06–1.47;  $I^2 = 22.8\%$ ).

In the subgroup analysis, the pooled measure (OR, 1.32; 95% CI, 1.18–1.48;  $I^2 = 44.8\%$ ) did not change materially for  $\leq 5$  h sleep duration [4,5,8–11,21–23], whereas the between-study heterogeneity declined. For higher cut-off of short sleep duration ( $\leq 6$  h) [6,24], the pooled OR was 2.74 (95% CI, 1.91–3.94;  $I^2 = 0.0\%$ ). Based on follow-up years, the combined measure was 1.37 (95% CI, 1.18–1.60;

**Table 1**

Characteristics of prospective studies on sleep duration and obesity.

Author, year [ref.]	Age (year)	Follow-up (year)	Country	Sex	Sample size	OR (95% CI) for short vs referent	OR (95% CI) for long vs referent	Sleep category (h)	Adjustment for covariates	Assessment of sleep duration
Chaput et al. 2010 [6]	18–64	6	Canada	M & F	151	2.97 (1.68,4.34)		Referent: 7–8 Short: $\leq 6$	Age, sex, baseline BMI, length of follow-up, and socio-economic status	On average, how many hours do you sleep a day?
Kobayashi et al. 2012 [21]	>20	3	Japan	M & F	11,136	1.5 (1.1, 2.0)	1.3 (0.9, 1.8)	Referent: 7 Short: $\leq 5$ Long: $\geq 8$	Age, gender, baseline BMI, alcohol drinking, exercise, hypertension, dyslipidemia, diabetes, cerebral infarction, and myocardial infarction	Average duration of sleeping time per night
Sayón-Orea et al. 2013 [9] <sup>a</sup>	39.1	6.5	Spain	M & F	10,532	1.94 (1.19, 3.18)	1.13 (0.89, 1.43)	Referent: 7–8 Short: $< 5$ Long: $\geq 8$	Age, sex, smoking status, physical activity, time spent sitting down, fast food, sugared soft drinks, snacking between meals, total energy intake, caffeine, alcohol, snoring, insomnia, siesta hours and baseline BMI	How many hours per day do you sleep at night during the weekdays? And during the weekends? (weekday sleep duration $\times 5$ + weekend sleep duration $\times 2$ )/7
Vgontzas et al. 2013 [10]	48.9	7.5	USA	M & F	815	1.08 (0.48,2.41)	1.43 (0.97, 2.1)	Referent: $\geq 7$ Short: $\leq 5$	Sleep difficulty, emotional stress, gender, race, age, AHI, BMI, age $\times$ BMI and depression	How many hours do you usually sleep at night?
Stranges et al. 2008 [22]	55	4	England	M & F	3786	1.05 (0.60,1.82)	0.91 (0.27,3.01)	Referent: 7 Short: $\leq 5$ Long: $\geq 9$	Age, sex, employment, alcohol consumption, smoking, physical activity and cardiovascular drugs, mental and physical scores (SF-36), depressive symptoms and use of hypnotics	How many hours of sleep do you have on an average week night?
Nagai et al. 2013 [8]	40–79	12	Japan	M & F	6162	0.96 (0.59,1.57)	1.06 (0.88,1.27)	Referent: 7 Short: $\leq 5$ Long: $\geq 9$	Sex; age; body mass index; education; smoking status; alcohol drinking; time spent walking/day; job status; marital status; menopause; coffee; self-rated health	How many hours on average do you sleep per day?
Patel et al. 2006 [4] <sup>a</sup>	52.4	12	USA	F	59,813	1.15 (1.04,1.27)	1.03 (0.93,1.14)	Referent: 7 Short: $\leq 5$ Long: $\geq 9$	Age, year of follow-up, and baseline BMI, smoking, alcohol consumption, caffeine intake, spousal level of education, medication use, menopausal status, snoring status, shift-working history, physical activity, total caloric intake, dietary fiber, ratio of polyunsaturated to saturated fat, trans-fat intake, and servings of fruits and vegetables	Total hours of actual sleep in a 24 h period
Itani et al. 2011 [23]	$\geq 18$	7	Japan	M	11,424	1.20 (1.09,1.32)	1 (0.51,1.94)	Referent: 5–7 Short: $< 5$ Long: $> 7$	Age class, eating habits, alcohol consumption, smoking habit, exercise habit, mental complaints, hypertension, hyperglycemia, hypertriglyceridemia, and hypo-HDL-cholesterolemia	What was your daily average sleep duration?
Watanabe et al. 2010 [5]	39.9	1	Japan	M	20,023	1.91 (1.36,2.67)	1.42 (0.69,2.96)	Referent: 7–8 Short: $< 5$ Long: $\geq 9$	Age, shift-worker, smoking, alcohol consumption, and physical activity, depressive symptoms	How many hours do you sleep on weekdays? And on the weekend? (weekday sleep duration $\times 5$ + weekend sleep duration $\times 2$ )/7
Xiao et al. 2013 [11]	51–72	7.5	USA	M	35,319	1.45 (1.06,1.99)	1.12 (0.84,1.49)	Referent: 7–8 Short: $< 5$ Long: $\geq 9$	Age, baseline BMI, race/ethnicity, marital status, educational level, self-reported health, smoking status, alcohol consumption, and coffee consumption	The amount of time they slept at night in a typical 24 h period over the past 12 months
Nishiura et al. 2010 [24]	40–59	4	Japan	M	2632	2.46 (1.41,4.31)	0.75 (0.35,1.62)	Referent: 7–7.9 Short: $< 6$ Long: $\geq 8$	Age, baseline BMI, current medication, family history of disease, smoking, drinking, exercise, preference for fatty food, skipping breakfast, snacking, and eating out	How many hours, on average, do you sleep during the night?

OR, odds ratio; CI, confidence interval; BMI, body mass index; AHI, apnea–hypopnea index; HDL, high-density lipoprotein.

<sup>a</sup> Hazard ratio was extracted.

**Table 2**

Pooled measures on the relation of sleep duration to obesity.

	Short sleep duration			Long sleep duration		
	No. of studies	OR (95% CI)	Heterogeneity $I^2$ (%)	No. of studies	OR (95% CI)	Heterogeneity $I^2$ (%)
Overall	14	1.45 (1.25–1.67)	66.2	10	1.06 (0.98–1.15)	0
Excluding HRs	12	1.48 (1.24–1.78)	64.4	8	1.10 (0.96–1.25)	0
Male	5	1.65 (1.24–2.19)	74.7	5	1.01 (0.84–1.22)	0
Female	5	1.25 (1.06–1.47)	22.8	3	1.11 (0.87–1.42)	34.1
Cut-off for short sleep duration						
≤5 h	12	1.32 (1.18–1.48)	44.8	–	–	–
≤6 h	2	2.74 (1.91–3.94)	0	–	–	–
Study location						
North America	5	1.46 (1.11–1.94)	76.1	2	1.04 (0.95–1.14)	0
Europe	2	1.45 (0.79–2.64)	62.1	2	1.12 (0.89–1.42)	0
Japan	7	1.47 (1.16–1.87)	66.4	6	1.09 (0.94–1.27)	0
Follow-up years						
>5	9	1.37 (1.18–1.60)	65.4	5	1.05 (0.97–1.14)	0
≤5	5	1.60 (1.17–2.18)	49.6	5	1.17 (0.89–1.55)	0

OR, odds ratio; CI, confidence interval; HR, hazard ratio.

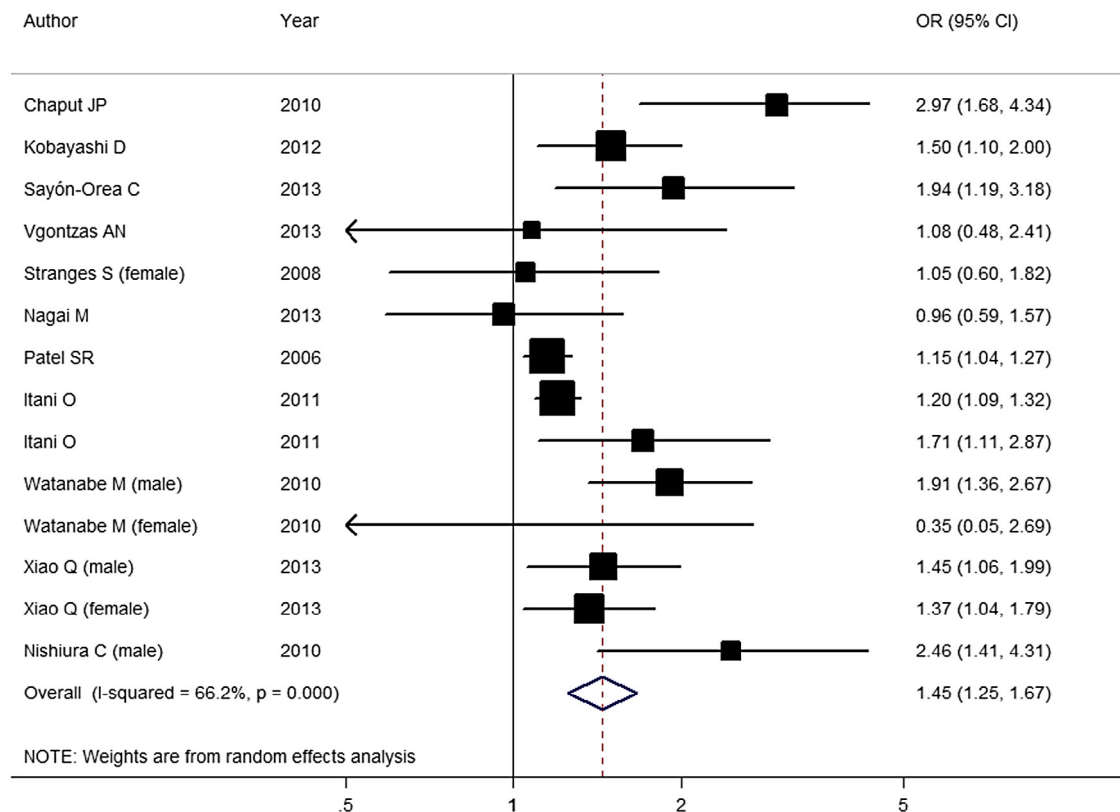
$I^2 = 65.4\%$ ) for >5 years [4,6,8–11,23] and 1.60 (95% CI, 1.17–2.18;  $I^2 = 49.6\%$ ) for ≤5 years [5,21,22,24]. The significant association was found among adults in North America [4,6,10,11] (OR, 1.46; 95% CI, 1.11–1.94;  $I^2 = 76.1\%$ ) and in Japan [5,8,21,23,24] (OR, 1.47; 95% CI, 1.16–1.87;  $I^2 = 66.4\%$ ), but not in Europe [9,22] (OR, 1.45; 95% CI, 0.79–2.64;  $I^2 = 62.1\%$ ).

### 3.2.2. Long sleep duration and obesity

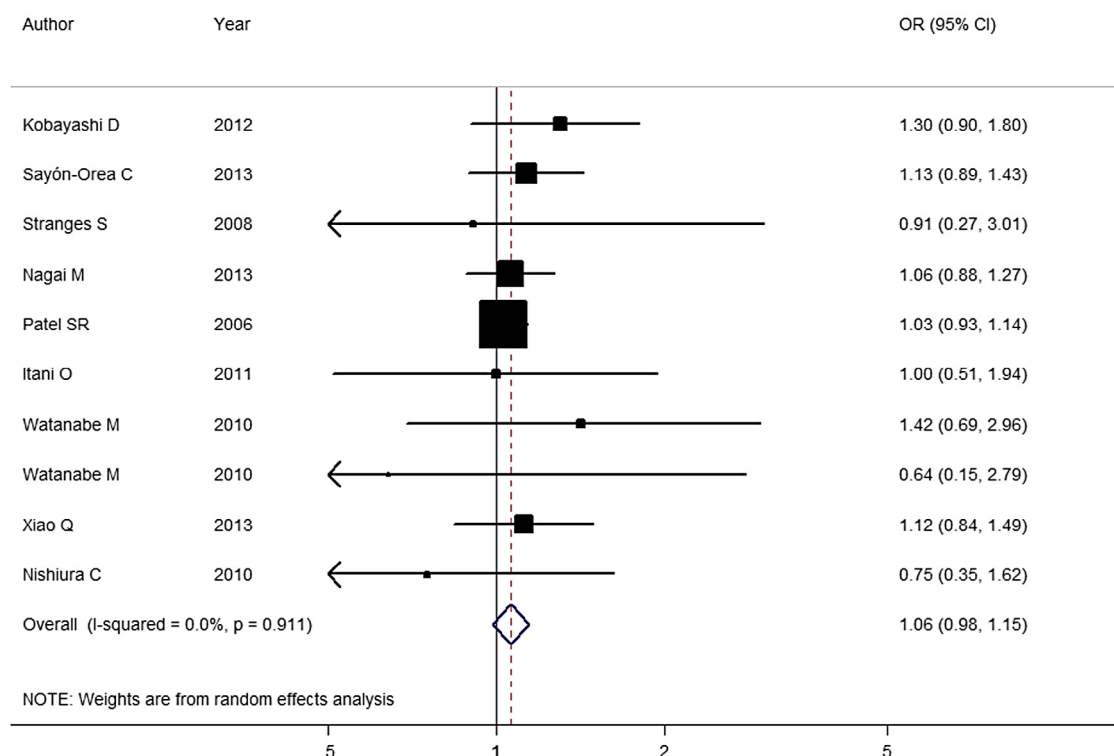
Two studies [6,10] did not assess the relationship between long sleep and obesity. One study [11] reported the OR value of obesity associated with long sleep duration in females without 95% CI.

In a Japanese study [23], no woman had long sleep duration. Therefore, 10 studies [4,5,8,9,11,21–24] involving 164,016 participants were included in the long sleep duration.

The overall result indicated no significant association between long sleep duration and incidence of obesity (OR, 1.06; CI, 0.98–1.15;  $I^2 = 0.0\%$ ) (Fig. 3). After excluding the studies reporting HR [4,9], the association (OR, 1.10; 95% CI, 0.96–1.25;  $I^2 = 0.0\%$ ) was still not statistically significant. The combined OR was 1.01 (95% CI, 0.84–1.22;  $I^2 = 0.0\%$ ) in males [5,9,11,23,24] and 1.11 (95% CI, 0.87–1.42,  $I^2 = 0.0\%$ ) in females [4,5,9], respectively. No association was found in all of the subgroup analysis.



**Fig. 2.** Forest plot of the odds ratios (ORs) with corresponding 95% confidence intervals (CIs) of studies on short sleep duration and obesity. The size of gray box is directly proportional to the weight assigned to each study, which is inversely proportional to the standard error of the OR; horizontal lines represent the 95% CIs.



**Fig. 3.** Forest plot of the odds ratios (ORs) with corresponding 95% confidence intervals (CIs) of studies on long sleep duration and obesity. The size of gray box is directly proportional to the weight assigned to each study, which is inversely proportional to the standard error of the OR; horizontal lines represent the 95% CIs.

### 3.3. Sources of heterogeneity and sensitivity analysis

Strong evidence of heterogeneity among studies was demonstrated for short sleep duration with obesity (Fig. 2). However, univariate meta-regression analysis, with the covariates of follow-up duration, study location, sample size, and the number of covariates adjusted in the multivariate model showed that no covariates had a significant impact on between-study heterogeneity. By using the sensitivity analysis, three articles [5,6,24] contributed to this high between-study heterogeneity. After further excluding these three articles, low heterogeneity ( $I^2 = 24.8\%$ ) was found and the pool OR was 1.25 (95% CI, 1.14–1.38).

### 3.4. Influence analysis

In the influence analysis excluding one study at a time, the summary OR of obesity ranged from 1.37 (95% CI, 1.21–1.54) to 1.51 (1.27–1.80) for short sleep duration, and ranged from 1.05 (0.97–1.14) to 1.10 (0.98–1.24) for long sleep duration. All of the point estimates lay within the 95% CI of the combined analysis, indicating that no individual study had excessive influence on the pooled effect between risk of obesity and sleep duration.

### 3.5. Publication bias

Egger test showed no evidence of significant publication bias for the analysis between obesity risk and sleep duration ( $P = 0.07$  for short,  $P = 0.88$  for long; Figs. 4 and 5).

## 4. Discussion

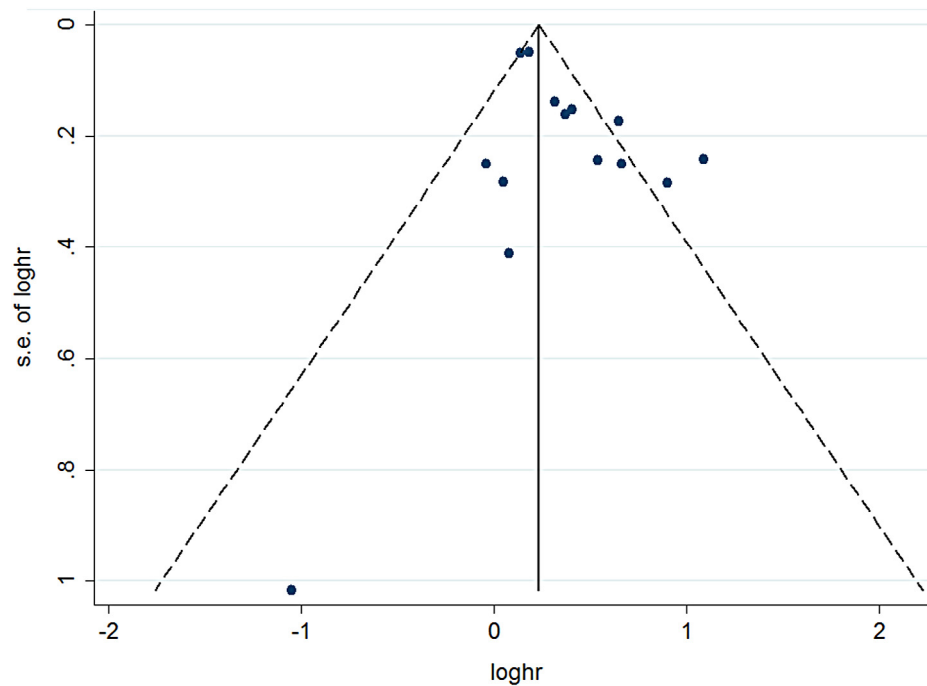
This study provides for the first time a meta-analysis of prospective-only studies examining the association between sleep duration and future obesity. The meta-analysis of prospective studies,

including 197,906 participants for short sleep duration and 164,016 participants for long sleep duration, strongly identified that short sleep duration was significantly associated with increased risk of obesity, whereas long sleep duration had no contribution to future obesity in adults.

The mechanisms underlying the association between sleep and obesity are still not fully understood. Several potential mechanisms exist by which reduced sleep may increase the risk of obesity [25]. First, evidence indicates that chronic sleep restriction leads to alterations in levels of appetite-regulating hormones such as leptin and ghrelin, which lead to increased appetite and subsequently increased food intake [26,27]. People with longer awake time have more opportunity to eat [28]. In addition, short sleep duration has been associated with fatigue and significantly reduced physical activity [4]. Our meta-analysis found no significant association between long sleep duration and obesity. Indeed, no biological mechanisms have been identified to explain their relationship [28].

Between-study heterogeneity occurs frequently in meta-analysis [12]. In this study, no heterogeneity was found in long sleep analysis, whereas moderate to high heterogeneity was found in short sleep analysis. Thus, we used meta-regression for short sleep that aimed to explore the potentially important causes for between-study heterogeneity. Meta-regression did not find the covariates of follow-up duration, location, sample size or number of adjustments in multivariate models as the important contributors to the heterogeneity. Other factors might also contribute to the heterogeneity. First, there was no standard definition for short/long sleep duration. The subgroup analysis based on definition of short sleep ( $\leq 5$  h and  $\leq 6$  h) found that the combined ORs were significant in both groups, whereas the  $I^2$  declined, indicating that the different definitions of short sleep across studies contributed to the high level of heterogeneity. Second, the study participants included in our meta-analysis were different, including general population based on various health programs [6,9–11,22], nurses [4], employees of companies



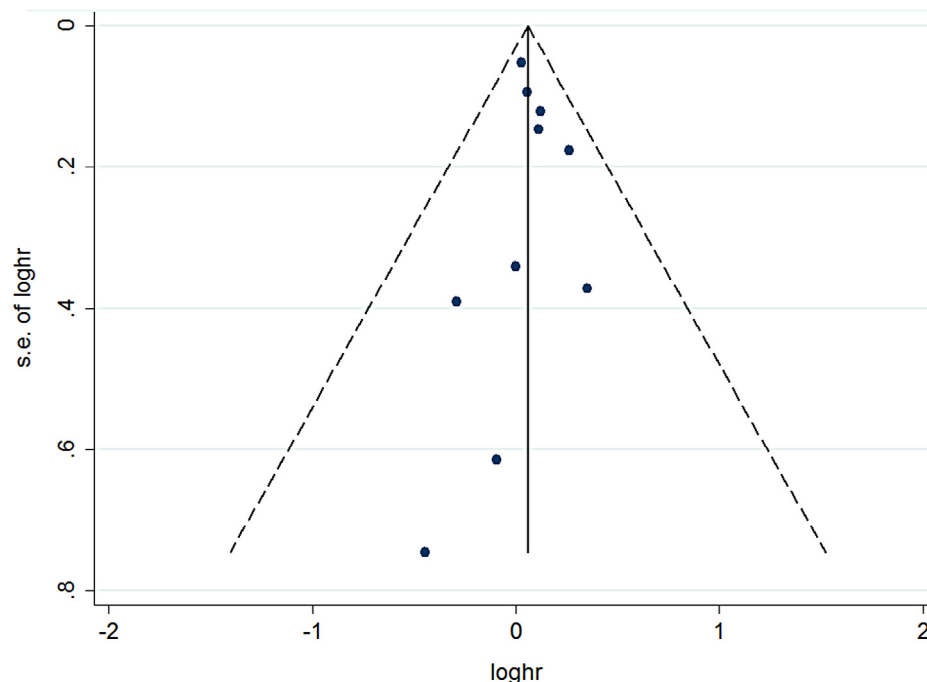


**Fig. 4.** Funnel plot of the odds ratios of 14 studies on short sleep duration ( $\log_{10}$  hours) and obesity. Each dot represents a different study. s.e., standard error.

or local governmental organizations [5,21,23,24] and national health insurance beneficiaries [8]. The difference in sample characteristics was a potential cause for the high heterogeneity [12]. For example, menopausal symptoms may play a role in the relationship between short sleep and obesity among middle-aged women such as nurses [4], and shift work could influence eating and exercise habits, resulting in an increased risk of obesity in some occupational staff [23]. Third, the definitions for obesity were BMI  $\geq 30$  kg/m<sup>2</sup> in European and American subjects as well as BMI  $\geq 25$  kg/

m<sup>2</sup> in Japanese subjects; however, one study [6] defined the outcome as overweight/obesity (BMI  $\geq 25$  kg/m<sup>2</sup> for French-Canadians), and the sensitivity analysis suggested that this study had a strong effect on heterogeneity.

Considering the difference between HR and OR, we conducted the analysis excluding the study reporting HR as the risk measure, and found that the results did not change in the analysis for both short and long sleep duration. Our sensitivity analysis for short sleep indicated that the positive pooled OR did not change materially with



**Fig. 5.** Funnel plot of the odds ratios of 10 studies on long sleep duration ( $\log_{10}$  hours) and obesity. Each dot represents a different study. s.e., standard error.

low heterogeneity after excluding the three articles that had strong effects on heterogeneity. In the subgroup analysis, the associations were consistent in different subgroups except for the pooled OR of short sleep in Europeans that is perhaps due to the small sample size (only two articles included). After subgroup analysis and sensitivity analysis, the association between short sleep and obesity was robust in this meta-analysis.

A major strength of this study was the large number of participants included from prospective studies, allowing a much greater possibility of reasonable conclusions. Compared with the most recent systematic review [7] on the same topic, the criteria for the study design in our meta-analysis were stricter. The systematic review included more studies observing weight gain (increasing BMI) as outcome, which did not exclude the obese individuals from the cohort at baseline. Our meta-analysis focused on the risk of new-onset obesity caused by short/long sleep duration.

There were some limitations to consider. First, although the random-effects model was used as the pooling method in our meta-analysis, moderate to high heterogeneity for short sleep duration analysis should not be ignored. Second, the information on sleep duration was self-reported by questionnaire for most studies. Only one study [10] assessed both subjective and objective sleep duration (its subjective results were extracted). Compared to actigraph-measured sleep, self-reported sleep duration might be influenced by poor sleep and emotional stress, which could lead to the incident obesity [10]. Third, although we extracted the ORs or HRs that reflected the greatest degree of control for potential confounders, the confounders controlled for were different among studies.

In summary, results from this meta-analysis indicated that short sleep duration was significantly associated with incidence of obesity, whereas long sleep duration had no effect on future obesity among adults. Considering the relatively small number of studies included in this meta-analysis, further studies are needed to confirm the findings.

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## Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <http://dx.doi.org/10.1016/j.sleep.2014.07.018>.

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